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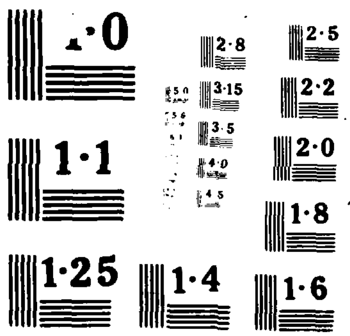
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FINAL SUMMARY REPORT

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MAINTENANCE, QUEUES AND NETWORKS, II:

COMPUTATIONAL PROBABILITY FOR LARGE-SCALE DYNAMIC SYSTEMS

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1. GENERAL COMMENTS AND SUMMARY OF ACCOMPLISHMENTS

1.1:

The discipline and application of stochastic operations research are, by their very nature, bound up with two conflicting objectives. On the one hand, a manager requires a model which matches reality well or else the resulting recommendations would be suspect. On the other hand, any mathematical model which is constructed must be amenable to manipulation or else no conclusion at all would follow. Moreover, the result of an operational study should yield more than simply a recommendation, but also some new insight into the relationships involved. In light of today's easy access to large and inexpensive computer resources, computational complexity is no longer to be avoided as in the past, and it is thus now much easier to tackle large and possibly very difficult problems.

The potential tension between reality and complexity can be seen in this year's continuing focus on the computational feasibility of the very broad class of probability distributions characterized as "generalized hyperexponentials" (GH). Typically, in general stochastic modeling, computational feasibility has at least two important aspects. One is the development of rapidly converging algorithms for the solution of numerical (usually optimization) problems arising in the use of any class of probability distributions in modeling. Second is the high quality of their use in closed-form approximations for "real" systems (in our work, particularly those which may arise in maintenance and network analyses). The GH family possesses both traits. This class of probability distributions has several important properties (namely, closure under

mixture and convolution, completeness, and identifiability) which guarantee in advance of model construction that the mathematical operations will lead to an attractive solution procedure.

At the realism end of the spectrum, our work on server-vacation problems extends the current understanding of an important, emerging area of application, namely, local-area network models of computer/communication systems. We have tied the vacation problem to the classical concept of queues with state-dependent service, and developed some schemes for the critical calculations of state probabilities and waiting-time distribution functions.

Our work on sampling has concentrated on two problem areas: the development of effective strategies for distribution modeling and for the sensitivity analysis of very large stochastic models. Our modification of the classical Latin square to the so-called Latin hypercube sampling plan appears to maximize the information about a distribution function (in the sense of minimizing the estimate's variance subject to fixed sampling resources). As part of this effort, we have coded the Latin hypercube plan, and experiments suggest that our programs are very efficient.

1.1.1 The following manuscripts were completed:

Harris, C.M., Botta, R.F. and Marchal, W.G., "Mathematical and Statistical Characterizations of Generalized Hyperexponential Distribution Functions," Report No. GMU/49146/101, tentatively accepted for publication by Stochastic Models.

ABSTRACT

This paper examines in detail the class of generalized hyperexponential (GH) probability distribution functions. The family is compared to and contrasted with similar popular classes of distributions used in stochastic modeling. Each of these families arises from a desire to preserve the computationally attractive feature of "memorylessness" possessed by the exponential probability distribution while extending the representations to a broader class in order to approximate an arbitrary probability distribution function. Thus, the simple structure and attractive properties of the GH probability distribution functions are presented with a view toward facilitating the mathematical operations which frequently occur in practice.

Harris, C.M. and Marchal, W.G., "State Dependence in M/G/1 Server-Vacation Models," Report No. GMU/49146/102, tentatively accepted for publication by Operations Research.

ABSTRACT

This paper examines a generalization of the exhaustive and one-at-a-time-discipline M/G/1 vacation models. This alternative model is viewed as a state-dependent (non-vacation) M/G/1 queue in which the original service times are extended to include a

(possibly zero length) state-dependent vacation after each service. Such a vacation policy permits greater flexibility in modeling real problems, and does, in fact, subsume most prior M/G/1 approaches. This device reveals a fundamental decomposition somewhat like that previously established for the classical vacation disciplines. In addition, necessary and sufficient conditions for system ergodicity are established for the state-dependent vacation policy, and some comments are offered on computations together with a few illustrative examples.

1.1.2 The following paper was published:

Botta, R.F. and Harris, C.M., "Approximation with Generalized Hyperexponential Distributions: Weak Convergence Results," Queueing Systems, Volume 1, Number 2, pp. 169-190 (1986).

ABSTRACT

See report for fiscal year 1985.

1.1.3 The following papers are scheduled for publication:

Harris, C.M. and Sykes, E., "Maximum Likelihood Estimation for Generalized Mixed Exponential Distributions," to appear in Naval Research Logistics Quarterly, c. February 1987.

ABSTRACT

See report for fiscal year 1985.

Harris, C. M., "Estimating Quantiles by Simulation: A Brownian Motion Example," to appear in Journal of Statistical Computation and Simulation, 1987.

ABSTRACT

See report for fiscal year 1985.

Harris, C.M. and Prabhu, N.U., "Stochastic Comparison of Single-Server Queues," to appear in Naval Research Logistics Logistics Quarterly, 1987.

ABSTRACT

See report for fiscal year 1985.

1.1.4. The following talks were given:

Harris, C.M., "Mathematics and Statistics of Generalized Mixed Exponential Distributions," to Washington Statistical Society, 18 October 1985.

ABSTRACT

This talk focused on the broad class of probability distribution functions consisting of all those which may be written as linear (not necessarily convex) combinations of negative exponentials. The question of the completeness of such distributions as approximations in the space of all CDFs was discussed as a measure of the potential usefulness of this family. A nonlinear optimization algorithm has been developed for estimating the parameters of the most general form of the exponential mixtures from raw data (possibly even censored). Some computational experiences in its use were offered, and a number of applications were discussed.

Harris, C.M., "Sampling Proceeding in Order of Size," Fall 1985 Meeting of ORSA/TIMS, Atlanta, Georgia, 4 November 1985.

ABSTRACT

In this talk, we attempted to show how probabilistic and statistical methods may be used to try to answer fundamental questions on sampling in order of size, with discussion separating into nonparametric and parametric assessments. Our nonparametric work focused on some classical rank procedures. A hypothesis test was offered for the order question which allows the incorporation of size information. In our discussion of parametric approaches, we explored some well-known procedures and discussed their ability to answer the key questions. In response to some of their difficulties, we offered alternative thoughts.

Harris, C.M., "Statistical Sampling Procedures for Sensitivity Analysis," Spring 1986 Meeting of ORSA/TIMS, Los Angeles, California, 14 April 1986.

ABSTRACT

The generation of efficient sampling plans is often of critical importance when working with large-scale, computer-based models. Multi-dimensional variations of Latin squares have found application in model sampling, but their efficient creation by computer requires a detailed understanding of the geometry of such Latin hypercubes. We have thus attempted to use these geometric properties to improve computational effectiveness.

1.2:

Steady-state conditions of a stochastic system are typically expressed by stating that the expected fluctuation of a certain random variable, or a random process, is zero. Such a variable or process is said to be balanced. In the context of queueing theory and applications, such balanced processes are number in system, number in queue, virtual delay, backlog, aggregate remaining sojourn, and others. The method of systematically exploiting such balanced processes is called the conservation method.

The omni-method, an important example of conservation, starts with the simple and natural observation that, if X is a balanced process, then so is an arbitrary function of X.

Working out the balance equation for this arbitrary function of X has turned out to be a method which has led to a number of new results and insights and to a far reaching simplification in the derivation of some known results. Thus much of the theory of single-server queues with Poisson input and general service times follows from a simple omni-equation which yields all the moments of the delay and queue-size, their convolution equations, their Laplace transforms and generating functions, and more. Adding a vacation feature to the above queueing model requires only a small modification of the balance equation. In particular composition properties, now in vogue, are easily detected and derived with the aid of omni-equations.

The omni-method has done for the above queueing model everything that the method of inbedded Markov chains has done and more--and we believe in Markov and semi-Markov chains. The problem of so-called first passage to

a given state has been extended by allowing the cost of passage (or several cost elements of the passage) and by replacing the single given state by a set of states (a "superstate"). The results will be described in a future report.

In addition to the omni-method we developed a so-called double matrix method for the treatment, under steady-state conditions, the size of the queue and system under first-in-first-out condition (or equivalent to this condition). This method has some desirable convergence properties which make it suitable for numerical work.

1.2.1. The following manuscripts were completed:

Krakowski, Martin, "System Size in Some Variants M/G/1," Report No. GMU/49146/104, submitted to Stochastic Models.

ABSTRACT

For some queueing models with Poisson input and the first-in-first-out property (this includes the model M/D/c) the size probabilities for the queue and the system can be formulated in terms of (1) the transit equation which relates the size of the system, as seen by a departing customer, to the size of the queue left behind by this customer upon entering the service station; and (2) the static equation which relates the queue size to system size at a random instant. When the solutions are stated in matrix form the matrices are stochastic; this assures the convergence of an iterative algorithm for computing the state probabilities. The methods presented in this paper are direct methods, that is, they are obtained without recourse to, or specialization of, the equations for the process "waiting for service" or "time spent in the system." The indirect methods based on these processes can be very effective, especially when one is

interested in both line delay time and queue size. For some vacation models the indirect methods are the simpler ones. However, we will deal with these indirect techniques in a future report. An inkling of their flavor can be sensed from the Appendix on The Poisson Transform.

Krakowski, Martin, "M/G/1 with Retinue," Report No. GMU/49146/105.

ABSTRACT

The model M/G/1 is modified in the following manner. The server is idled when he runs out of customers and resumes serving when the (m+1)st customer arrives, with m+1 referred to as the "initial quorum" and m the maximal queue size (and system size) while the server idles or vacations. The modified model is designated as M/G/1/(m). When m=0 we have the regular M/G/1. In Section 1 we derive several decomposition properties for the backlog and for the delay. In particular, we find that the backlog is distributed like the sum of the backlog in M/G/1 and a random variable which depends on the service time; and that the delay is distributed like the sum of the delay in M/G/1 and a random variable which depends on the service time and on the interarrival time.

1.2.2 The following paper is scheduled for publication:

Krakowski, M., "The Omni-Transform in Single-Channel Queues," to appear in Annals of Operations Research, c. December 1986.

ABSTRACT

See report for fiscal year 1985.

1.2.3 The following talk was given:

Krakowski, Martin, "Queues with Poisson Input Subject to FIFO," Spring 1986 Meeting of ORSA/TIMS, Los Angeles, California, 16 April 1986.

ABSTRACT

Based on the FIFO property, a unified treatment was presented for the process "number in system" in the models M/G/1, M/D/c and some extensions. The treatment used the so-called omni-transform which was already applied to "waiting time for service" and to some other stochastic processes.

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